Technology Validation of the Inertial Stellar Compass (ISC)

Tye Brady (tbrady@draper.com)

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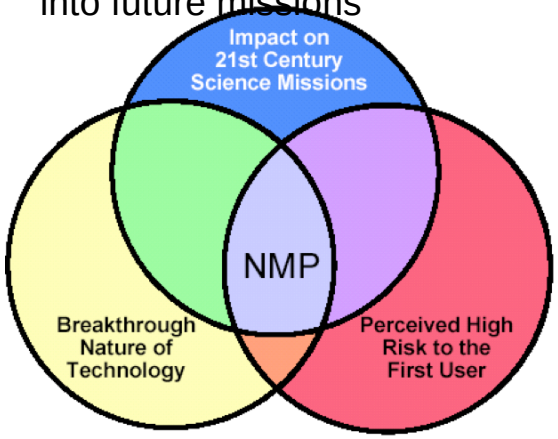
Abstract: Draper's Inertial Stellar Compass (ISC) is a real-time, miniature, low power stellar inertial attitude determination system, composed of a wide field-of-view active pixel sensor (APS) star camera and a microelectromechanical system (MEMS) gyro assembly, with associated processing and power electronics. The integrated APS and MEMS gyro technologies provide a 3-axis attitude determination system with an accuracy of 0.1 degree at very low power and mass. The attitude knowledge provided by the ISC is applicable to a wide range of Space and Earth science missions that may include the use of highly maneuverable, stabilized, tumbling, or lost spacecraft. Under the guidance of NASA's New Millennium Program's ST-6 project, Draper has developed the ISC. Its completion via flight validation will represent a breakthrough in real-time, miniature attitude determination sensors. The presentation describes system design, development, and validation activities in progress at Draper.

ISC Program at Draper

- **Objective is to develop new type of spacecraft attitude sensor**
  - ~36 months
  - ~$10M program
- **NASA's New Millennium Program, Space Technology 6 Project (JPL)**
  - Breakthrough technologies
    - Enable new capabilities to meet space science needs
    - Reduce costs of future missions
  - Flight validation
    - Mitigates risks to first users
    - Enables rapid technology infusion into future missions



NMP graphic courtesy of Chris Stevens, JPL New Millennium Program

The Flight ISC

Tye Brady
tbrady@draper.com

Inertial Stellar Compass (ISC)

Camera/Gyro Assembly

Data Processing Assembly

Ultra low power, low mass, stellar inertial attitude determination system

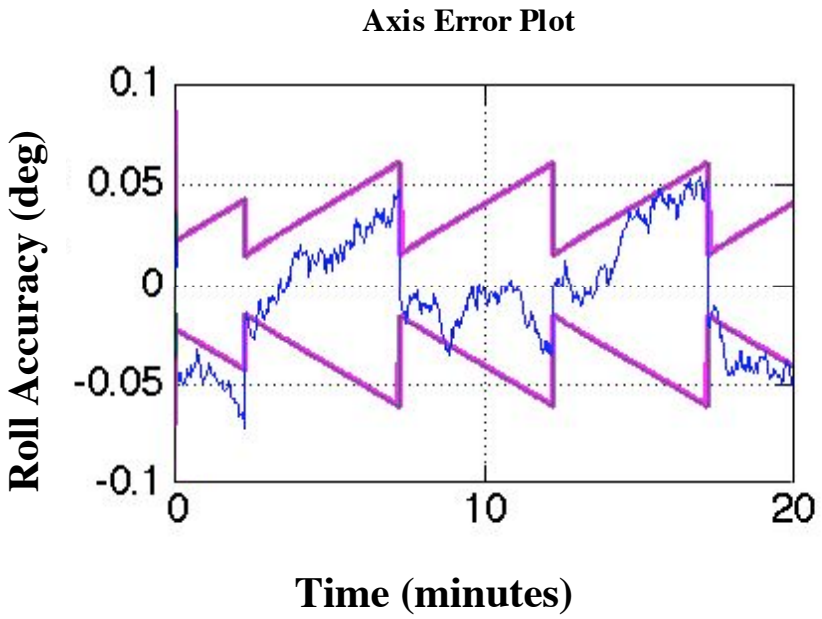
KEY FEATURES

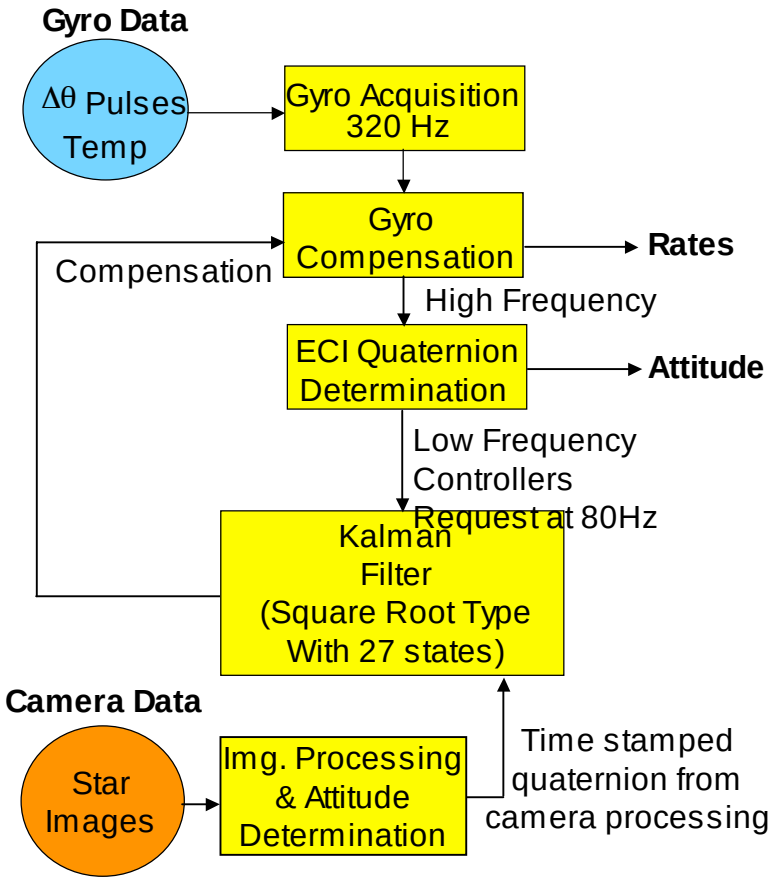
- ***~ 3.5 W***
- ***~ 2.9 kg***
- ***Integrated "bolt-on" unit***
- ***Standalone attitude determination up to 40 deg/sec***
- ***Better than 0.1 deg accuracy***
- ***Self-initializing***
- ***5Hz output (quaternion, rates, error)***

Tye Brady
tbrady@draper.com

Fusion of Gyros and Camera Data

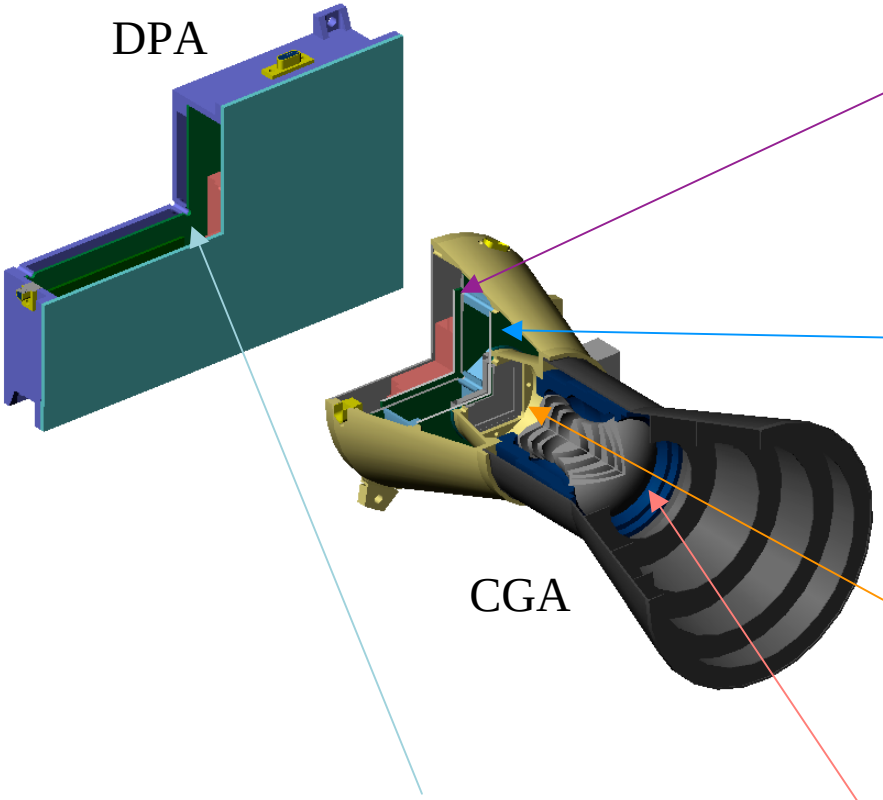
- **Camera updates gyros every couple of minutes**
  - Camera has Lost-in-Space capability
  - Gyro bias, scale factor, and misalignment errors reduced real time





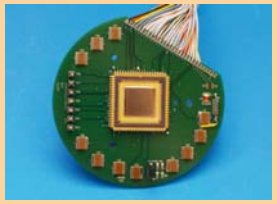
Tye Brady
tbrady@draper.com

Inertial Stellar Compass Hardware

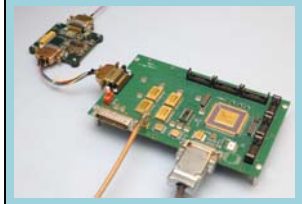


Controller board blends camera and gyro command and control into a single interface

3-axis MEMS gyros provide attitude and mitigate star camera optical interference and high rate slewing problems



Low power active pixel sensor acquires star images and provides attitude truth for gyro drift, bias calibration, and self initialization

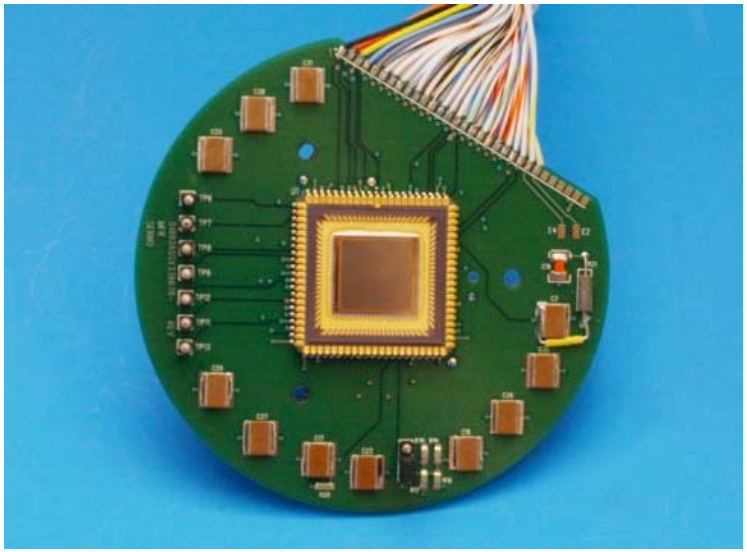


Software running in ERC32 processor blends gyro and camera data

Space capable Zeiss lens leverages commercial grade Distagon lens

Tye Brady
tbrady@draper.com

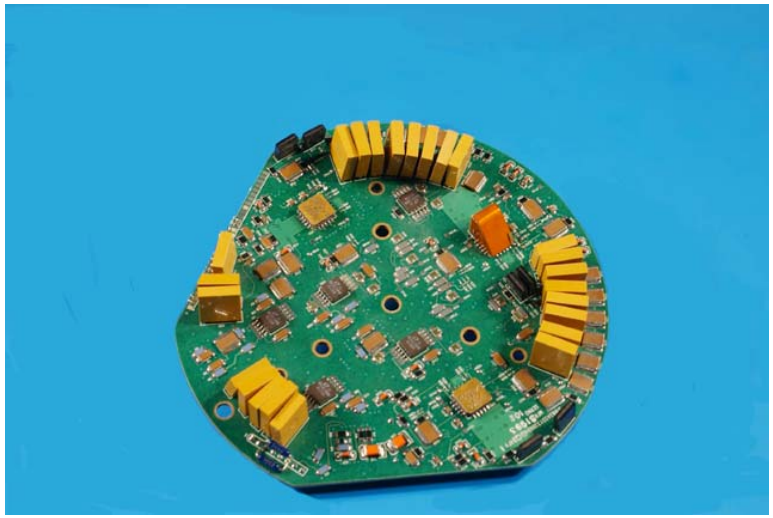
Star Camera Design



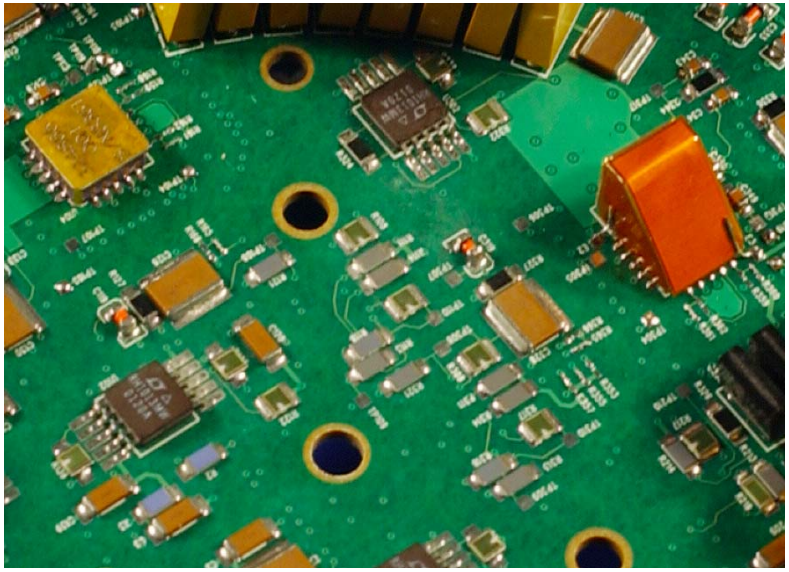
- **21º square FOV**
- **35mm f/1.2 Lens**
- **512 x 512 pixels**
- **Sees 1500 brightest stars in sky**
- **0.4 W**
- **37” in roll and 18” in pitch and yaw (1 sigma)**

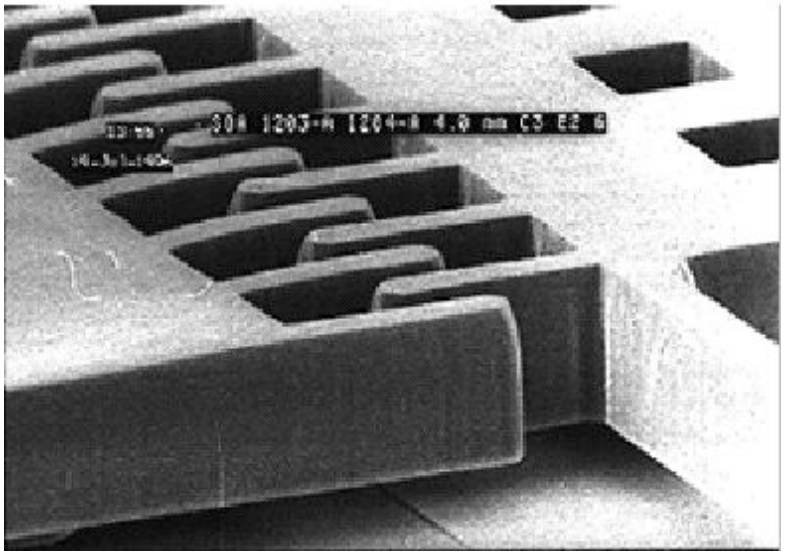
Tye Brady
tbrady@draper.com

Gyro Design



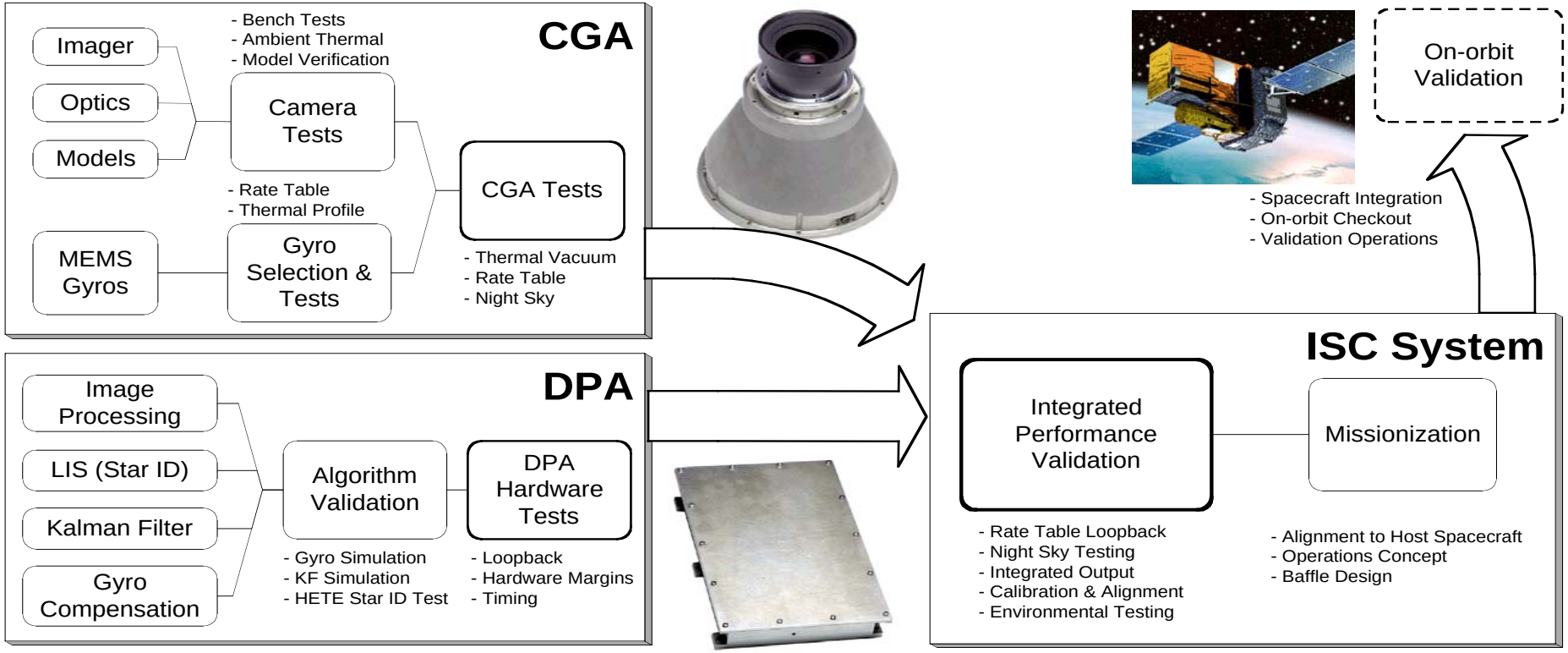
- **Maximum Input Scaling: 40°/s**
- **Board Power = 0.90 W**
- **Sampling rate: 320 Hz**
- **Performance**
  - Bias Drift Rate = 3.3°/hr
  - Angle Random Walk = 0.16 °/rt-hr
  - Scale Factor Error = 100 PPM





Tye Brady
tbrady@draper.com

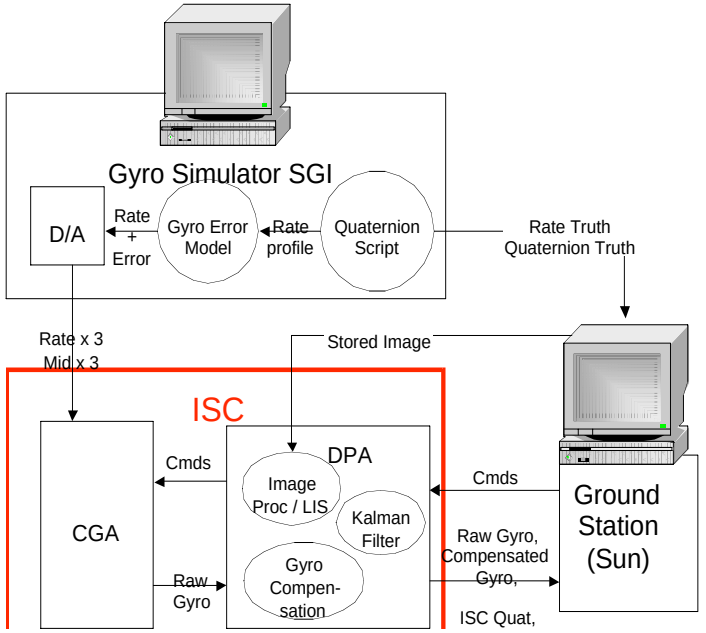
Ground Validation Process

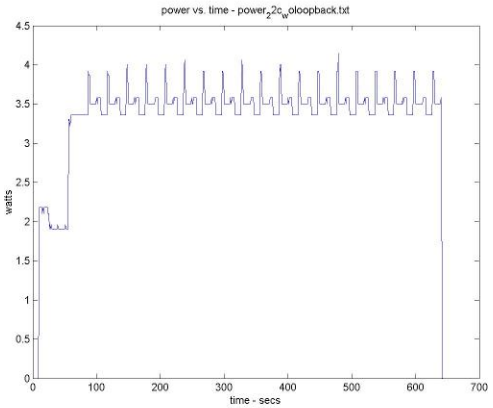


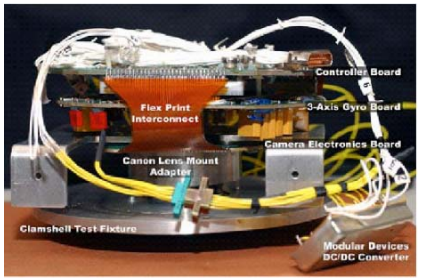
Tye Brady
tbrady@draper.com

Bench Performance Testing

- Bench Test Approach
  - Integrate and checkout all flight boards into single electrical system
  - Perform functional level tests on integrated system
  - Verified
    - Power draw
    - Interface checkouts
    - Packaging approach
- Gyro Simulator
  - D/A in place of gyro sensors
    - Generate any rate or position profile
    - Generate any gyro errors
- Loopback Mode
  - ISC software running while processing prerecorded images and real or simulated gyro
  - Mode to be used during all spacecraft I&T

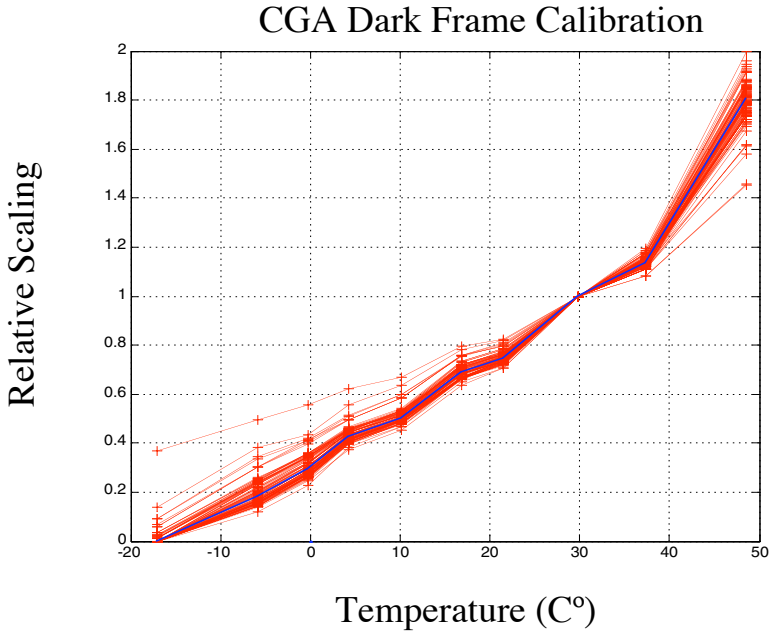




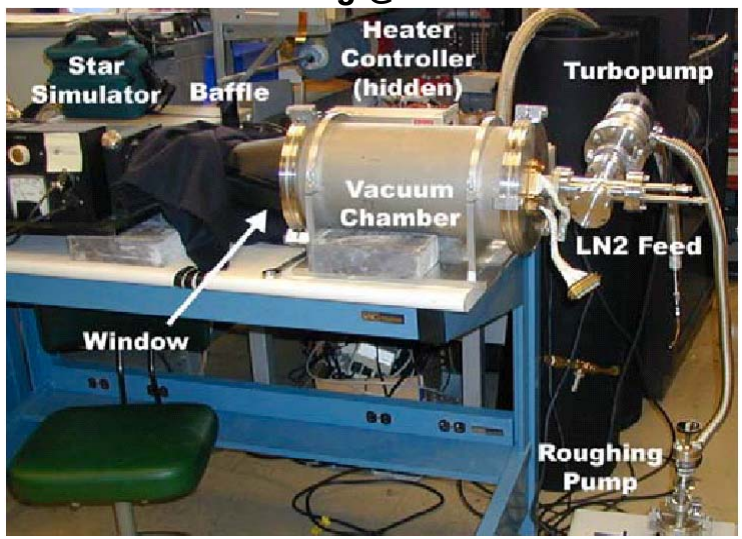


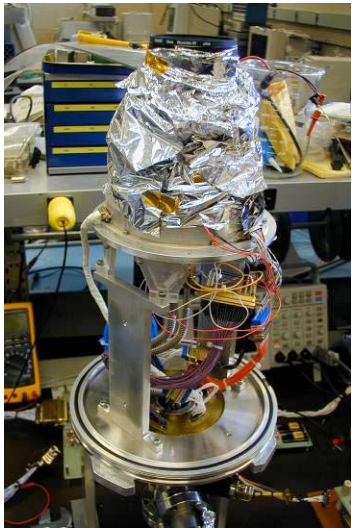
Tye Brady
tbrady@draper.com

Thermal Vacuum Tests



TVAC testing @ MIT





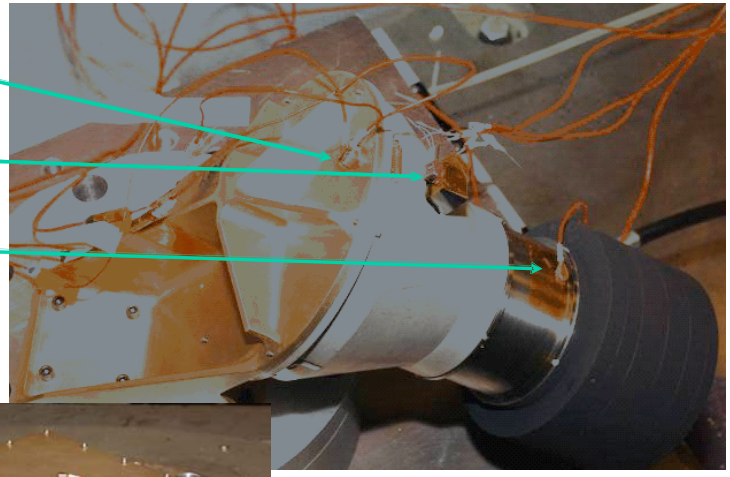
- Approach
  - ISC subject to relevant space-like environment (vacuum and temperature)
- Tested/Measured
  - Focus, Survival, Dark Frame, Noise Equivalent Angle

Tye Brady
tbrady@draper.com

Vibration and Shock Testing

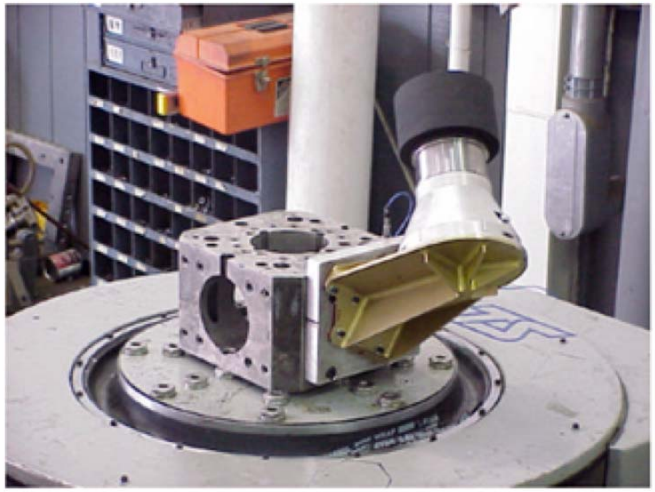
Vibration Testing @ Draper

- Three axis accel on back of bracket
- Three axis accel on CGA cube
- Single axis accel on throat of baffle
- Single axis control accel on fixture (out of view)



CGA (above) and DPA (left) on shaker table

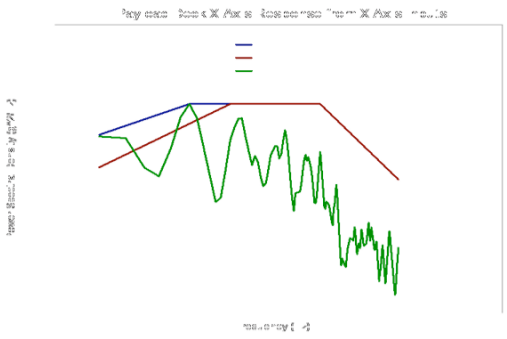
Shock Testing @ NTV in Los Angeles

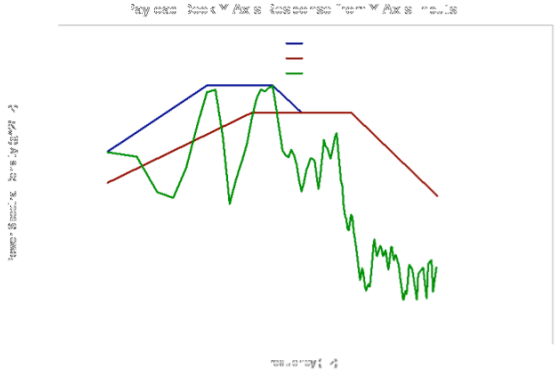


CGA (Mass Model), X-Axis Shock Setup

CGA tested: ~17grms, ~14grms, ~10grms

DPA tested: ~11grms, ~10grms, 11grms

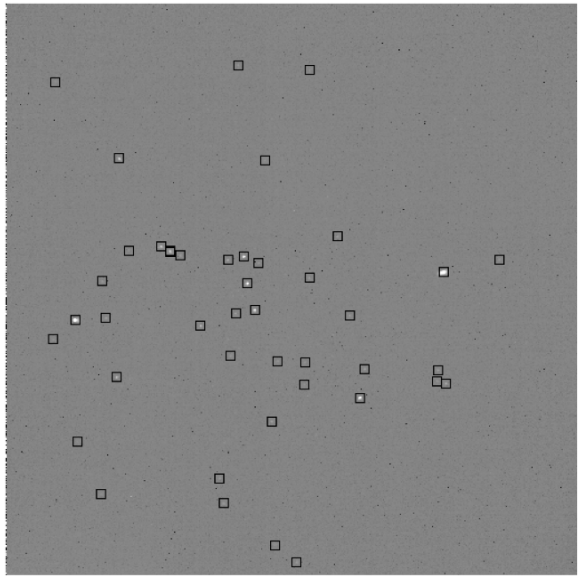




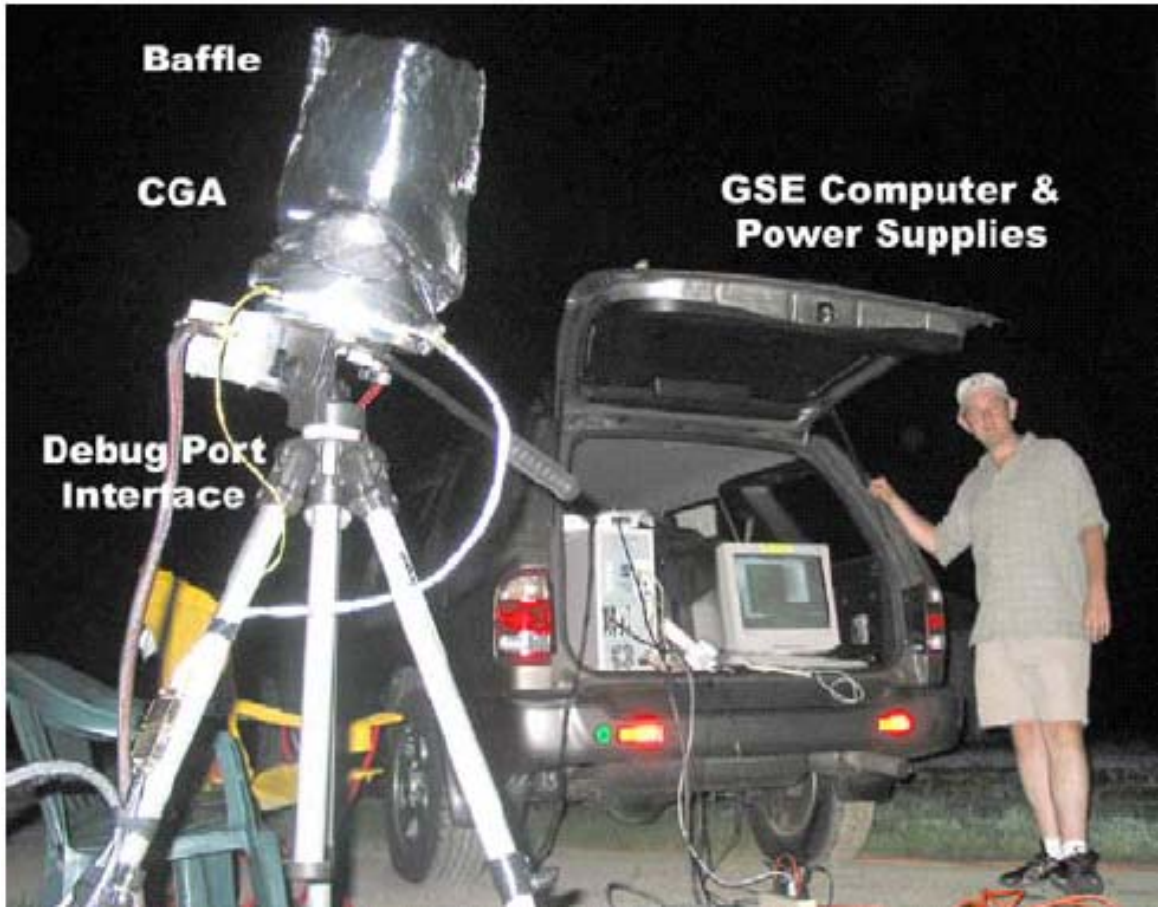
Tye Brady
tbrady@draper.com

Night Sky Test

- **Approach**
  - Field tested integrated ISC camera to look at real night sky images
- **Tested/Measured**
  - Image processing
  - Sensitivity
  - Focal length calculations
  - Lens distortions

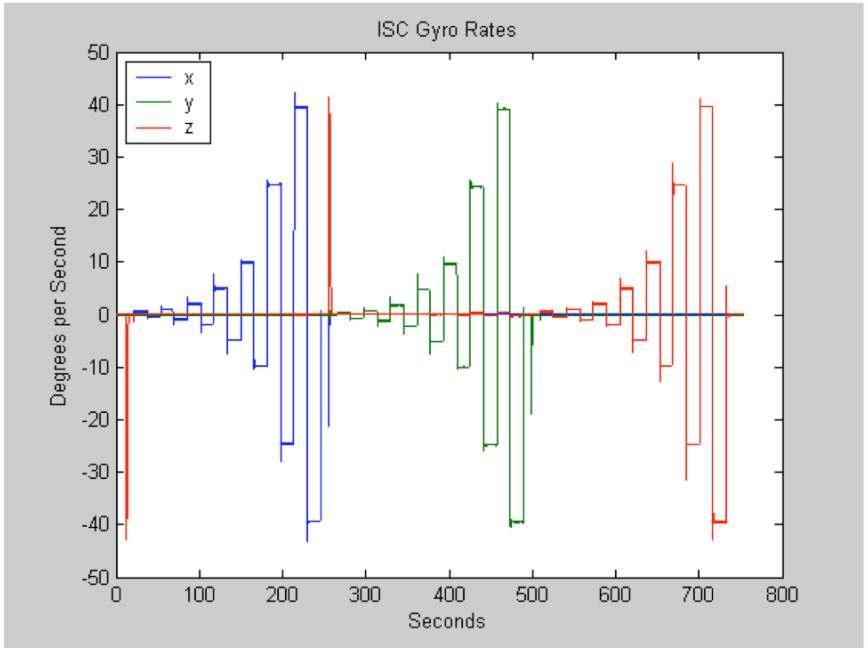


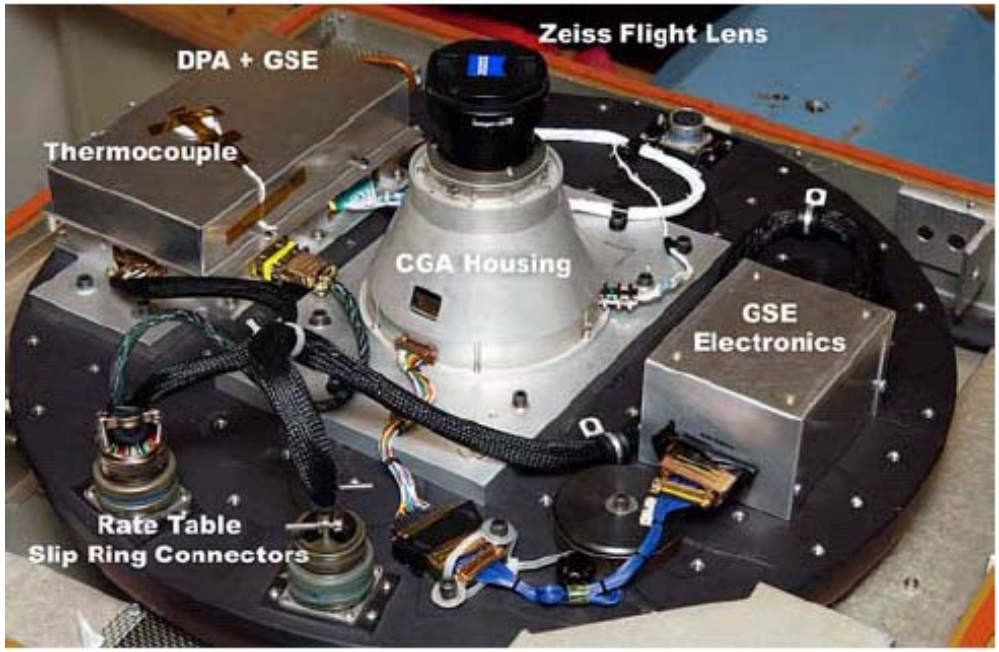
Night Sky at Wallace Observatory 08/14/03



Tye Brady
tbrady@draper.com

Rate Table Testing





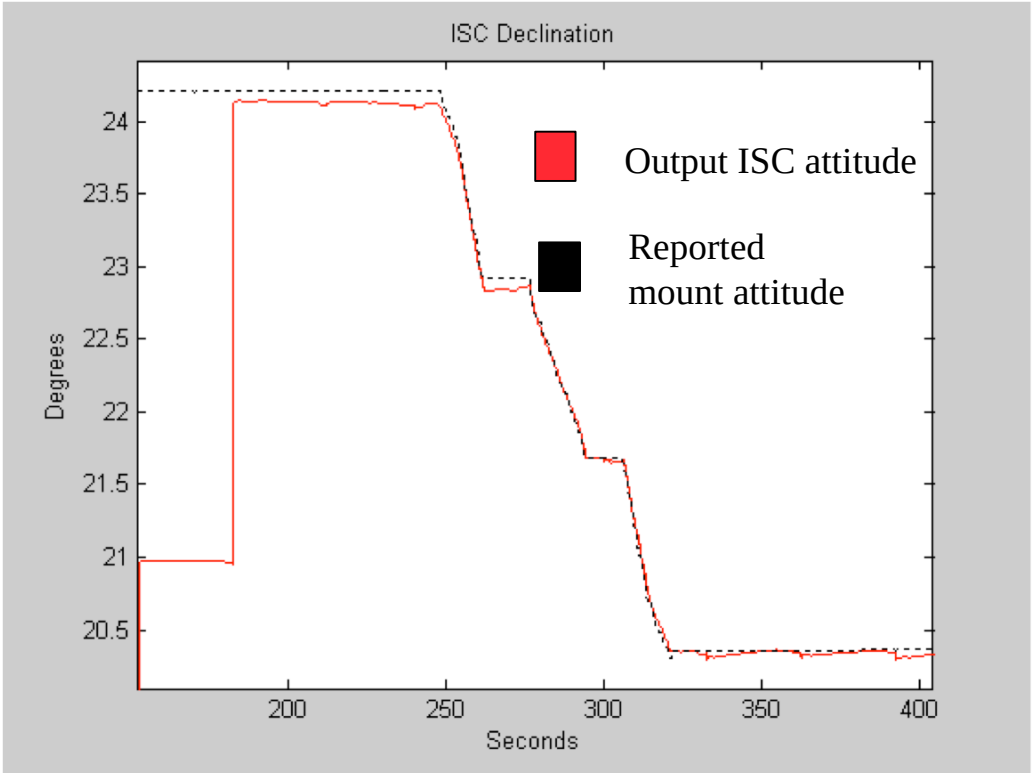
Rate Table Testing at Draper

- **Approach**
  - Integrated CGA and DPA on two-axis thermal rate table
- **Tested**
  - Ability for MEMS gyros to sense rate over various rates and temperatures
  - Integrated output of MEMS gyros over various test scenarios

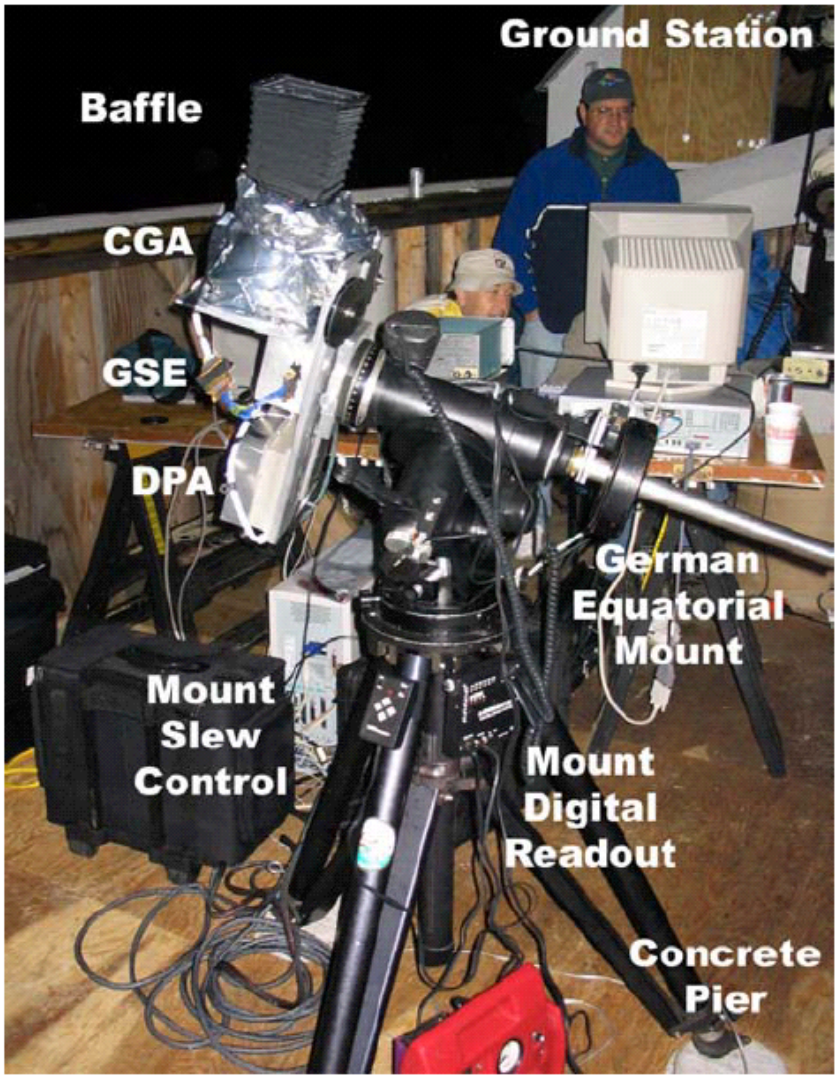
Tye Brady
tbrady@draper.com

Observatory Tests

- **Approach**
  - Verify integrated ISC output relative to calibrated telescope mount over various rates and crude thermal profiles
- **Tested/Measured**
  - Integrated ISC output



Night Sky at Haystack Observatory 9/24/03



Tye Brady
tbrady@draper.com

Exceeds Customer Requirements

Criteria	Requirement	Measurement
Mass	3 kg	2.9 kg
Power	4.5 W	3.5 W
Accuracy	0.1º	< 0.1 º
Space Qualified	Technology Readiness Level 8	Awaiting Flight Test

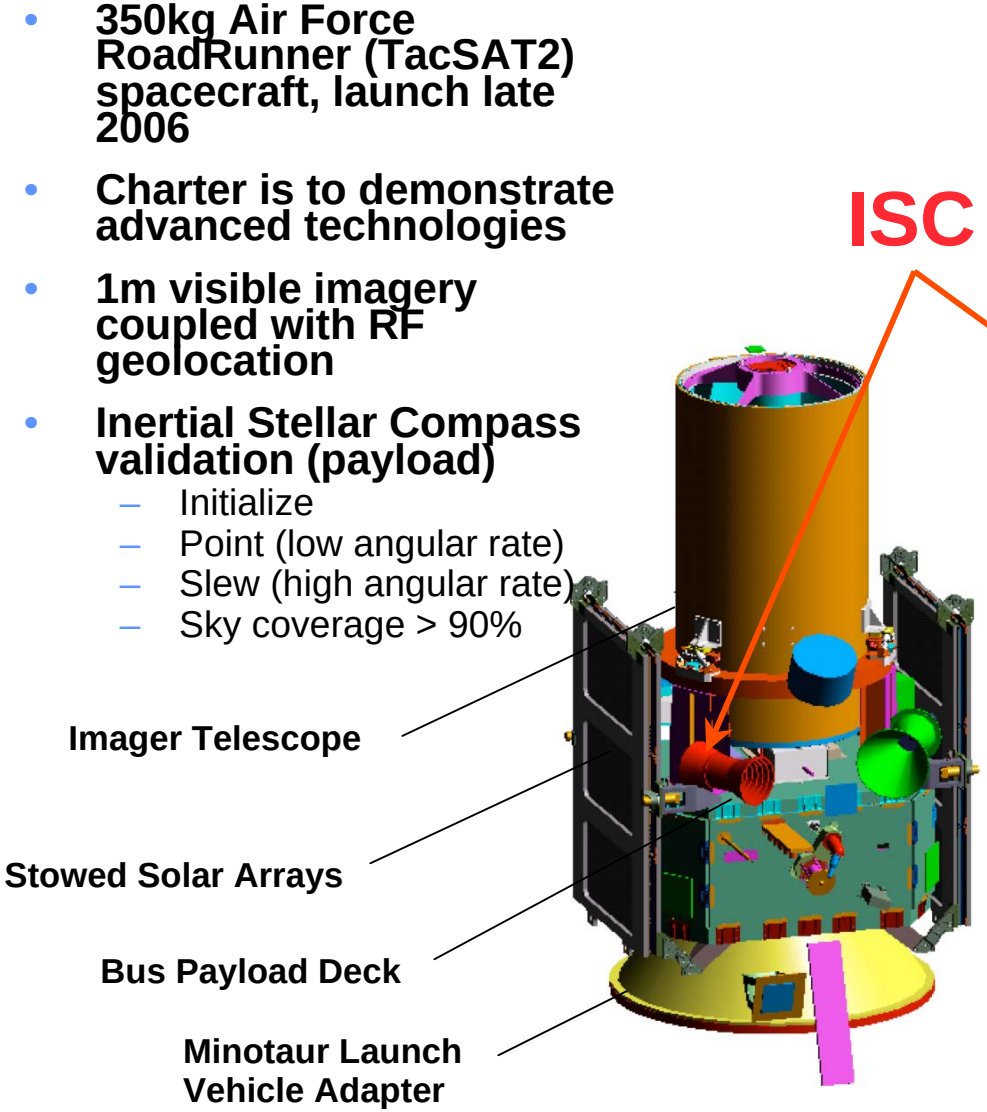
- **Status**
  - Flight-ready unit
  - Ground validation complete
  - On RoadRunner spacecraft, waiting for launch

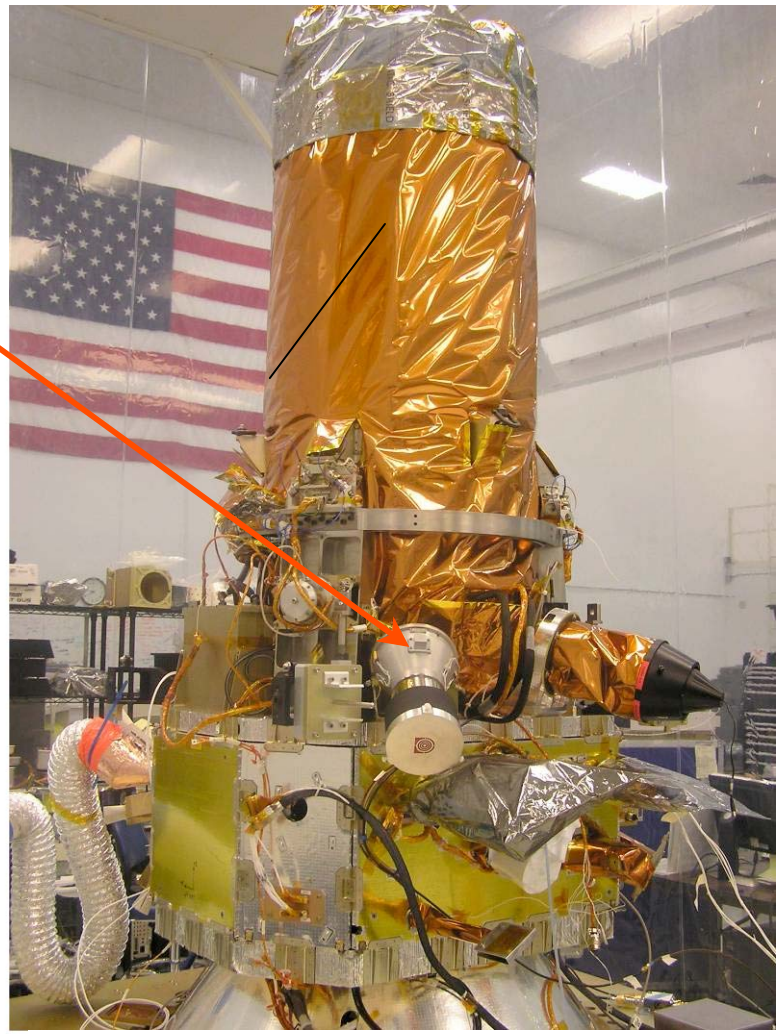
Achieves 0.1º attitude determination in a low mass, low power, bolt-on package

Tye Brady
tbrady@draper.com

Flight Validation

- **350kg Air Force RoadRunner (TacSAT2) spacecraft, launch late 2006**
- **Charter is to demonstrate advanced technologies**
- **1m visible imagery coupled with RF geolocation**
- **Inertial Stellar Compass validation (payload)**
  - Initialize
  - Point (low angular rate)
  - Slew (high angular rate)
  - Sky coverage > 90%





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